VALIDATION OF JABOWA

A NORTHEAST FOREST SIMULATOR

submitted to the Honors Committee

in partial fulfillment of

the requirements for

the Natural Resources Honors Program

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Columbus, Ohio

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November 12, 1975

ABSTRACT

JABOWA, a northeast forest growth simulator, is a computer program model designed for use on and with data from the Hubbard-Brook Experimental Forest in New Hampshire. In essence, the program predicts natural succession which would occur on a ten meter by ten meter plot with specified conditions, such as elevation, moisture and temperature levels, tree species, and soil-site factors including soil texture, depth and moisture holding capacity. In theory, the program can be used in other geographic areas and with tree species different from those in the original program. The subject of this report is the validation of JABOWA for use in Ohio forests and with Ohio forest data. The forest system in New England has different species, site and climatic factors, and dynamic interrelationships than found in Ohio. Therefore, a model developed for New England requires some change to predict Ohio growth trends.

A model such as JABOWA could be a valuable tool for forest managers to use as a guide for management decisions. Students could use the model in the classroom observing effects of various site factors on growth, succession, and management decision patterns.

To get an understanding of the terms "system," "model," and "simulation," a discussion is presented. Models such as JABOWA are based on a "systems" approach to problem-

solving; in other words, the unit being modeled is looked at in terms of interrelationships found between organisms, forces, substances and conditions within the system. To build a model of a system, one needs to understand the interrelationships between its subsystems. A simulation is a type of model which uses quantitative expressions to predict effects of changes in a subsystem on other subsystems.

Complexity of relationships in a forest system make it difficult to predict patterns of change within the system. However, a knowledge of interrelationships allows functional equations to be developed which can predict patterns in the system or its parts within certain limits.

Deviations from the "real world" in the program and the ramifications of these are discussed.

Before validation could begin, the program had to be revised to Ohio species, climate, soil and other site factors. This was accomplished with the help of a revision guide supplied by the designer, Dr. Daniel Botkin of Yale University.

Understory data supplied by Dr. James Brown of the Ohio Agricultural Research and Development Center, was used as a comparison for the simulated data. Trends of the real and simulated species compositions were not sufficiently compatible, thus proving, at least under the circumstances used for the test, JABOWA is not a valid predictor of growth patterns in Ohio forests.

The conclusion is discussed in the light of possible error sources in the program and basedata. Inadequate data and information sources, and steps that can be taken to alter the program to a more desirable state are considered.

TABLE OF CONTENTS

VALIDATION OF JABOWA

A NORTHEAST FOREST SIMULATOR

I. JABOWA - WHAT IS IT?

Introduction:

JABOWA, a northeast forest simulator, is a computer program designed as a continuation of the Hubbard-Brook Ecosystem Study. The model successfully reproduces the population dynamics of the trees in a mixed species forest of northeast United States. It was built to capitalize on data, environmental and site, species and tree growth, collected by F.H. Bormann and T.C. Siccama of Yale, G.E. Likens and R.H. Whittaker of Cornell, R.S. Pierce of the U.S. Forest Service, and their co-workers. Professor D.B. Botkin (Yale), Dr. J.F. Janak (IBM theoretical physicist) and Dr. J.R. Wallis (IBM research hydrologist) were responsible for all phases of the formulation and programming.

The complexity of a forest makes it hard to see relationships or predict effects of dynamics within the forest. The basic goal of the JABOWA program was to produce a dynamic model of forest growth. In the model, changes in the state of the forest are a function of its present state and random components of regeneration and death. A primary difficulty in developing the model arose in finding usable data regarding relationships between tree growth and environmental factors. When lacking data, simple yet reasonable relationships were synthesized, based on whatever knowledge and related data were available (5).

In theory, the program can be used, with modification, in other geographic areas and with species other than those used in the original program. A revision of the program is easily implemented using a guide provided by its three designers. It is the purpose of this investigation to attempt validation of the revised program using real data from Ohio forests. The validity of the program would be determined by the similarity between the simulated and real sets of data. It was hoped that with proof of validity, JABOWA could be used in an educational-management oriented aspect for Ohio foresters, forest land owners, and forestry students. This is discussed in a later section.

Backgrounds To Models And Simulations:

Since models such as JABOWA are based on a "systems" approach to solving a problem, the best approach to a discussion of models is through the definition of a system.

A system, whether social, economic or biological, can be defined as a set of interrelated parts which are highly interdependent and collectively exhibit a high degree of closure.

This concept can be illustrated using the example of a natural ecosystem. The ecosystem consists of all the living organisms, dependent on each other for food and recycling of nutrients, plus all the geophysical components such as soil, weather and geography, which are involved in and necessary for the continuation of the system. All living organisms of an ecosystem are interrelated through food chains; for example, a plant is eaten by an insect which is eaten by a bird which is eaten by a fox. The living organisms are also interrelated to the geophysical components which make up their habitat. Without a certain climate or geographical feature, certain species would not be able to exist.

A system exhibits a high degree of closure by being self-sufficient, self-regenerating or having distinct boundaries. This concept can be illustrated by looking at a watershed ecosystem. Closure is exhibited by the relative lack of external connections to other systems. Inputs into a watershed may be only a stream source, air and precipitation movement and limited emigration of animal and plant individuals. Interrelationships between the watershed system and other systems are very limited. The biological and geophysical processes going on within the boundaries of the watershed are much more interrelated and interdependent than external interrelationships. Therefore a high degree of closure is exhibited.

An understanding of these and many other interrelationships is desirable for the building and use of an ecosystem model such as JABOWA. What exactly is meant by the term "model"? It is a representation of the workings, interrelationships, changes within some system. It serves as a first approximation of the system, and it can later be built upon and improved. The model can be used as a forecaster of events. In the case of JABOWA, experiments too expensive or time consuming to be done in the real world can be carried out; i.e., the effects of environmental changes on a forest ecosystem.

The functions of the system conponents and the flows (interrelationships) between them can be represented by mathematical equations, a useful shorthand for describing complex ecological systems. These equations representing system behavior are quantitative expressions such as linear regressions or differential equations.

A mathematical model can be broken into four basic elements (12):

1) The state or condition of a system at any time is represented by sets of numbers, system variables. Different system variables characterize different components or subsystems of the system.

2) Functional relationship equations represent interactions between components.

3) Outside factors affecting components of the system are represented by forcing function equations.

4) Parameter is the term used for constants of

mathematical equations.

As an example, it might be determined that if an herbivore population is doubled, the amount of biomass consumed increases by 1.8. The removal of the extra vegetation results in 1.5 times as much solar energy reaching the soil surface. This increase in energy increases soil water evaporation which reduces the amount of precipitation in run-off. By obtaining quantitative expressions for these relationships, changes made in one subsystem can be traced through the system to see how other parts are affected by the initial change.

A simulation, such as JABOWA, is a model which can predict events extrapolated beyond the realm of historic data. In other words, instead of predicting within the limits of historic values, a simulator predicts outside of these bounds, yet based on the historic data. An example might be as follows:

Growth data for a stand of trees has been gathered covering twenty years of growth. Mathematical expressions representing growth trends for each species are formulated. These simulation equations should predict, within specific limits, growth trends of the stand past the twenty years of field data, to forty, sixty, eighty years of growth.

The system being simulated in the case of JABOWA is a forest ecosystem. A forest is a dynamic system of interrelated subsystems. The complexity encountered makes it difficult to attempt to synthesize knowledge or predict patterns of growth within the dynamic system, without the construction or use of a model. However, the relationships between subsystems, water, soil, sunlight, vegetation, can be roughly determined from past observations without understanding the internal workings of the components. The term understanding in this case, is thought of as the ability to see how a component is organized from simpler parts. In order to predict how a component of a system will behave it is not necessary to understand precisely how that component is structured internally (12). Once data on results of changes in relations between component parts of an ecosystem are known, a series of functional equations can be developed, as stated earlier, to represent these relationships. Predictions thus can be made about the system or its parts.

The Northeast Forest Simulator (JABOWA) is a model which, through a computer program, simulates the growth, birth and death of trees, the natural succession, on a northeastern U.S. forest plot. Values for site characteristics such as soil depth and moisture capacity, elevation, amount of rock present, or moisture storage capacity of the soil can be specified by the user. The program uses this data to adjust parameters which affect the birth, growth and death of various species. These three functions are dependent on the site requirements and characteristics of individual species and an element of chance, which is provided through a random number generator. The program establishes and grows trees according to the functional equations, which are modified by existing site conditions. The user can note the growth rates of trees and species composition of the stand over periods of up to 500 years.

DEVIATIONS:

Mention should be made of possible sources of error from within the program.

Any deviations from expectations suggest that the model is not a true representation of the real world. Several limitations can be pointed out.

The growth functions are based on the maximum known size of each species. The fact that very few trees ever reach this maximum size is not really taken into account, in terms of site factors affecting growth and death.

The concept of form and factors affecting form of individual trees has not been taken into account. At the time JABOWA was developed, no relationship had been established between height and diameter growth and factors such as growing degree days or site quality.

Other somewhat arbitrary assumptions were made to fill gaps in incomplete data. Species are treated in only two tolerance classes, tolerant and intolerant. Deviation can result because of this. There are species which are not easily placed in tolerant-intolerant classes. Intermediates such as these should be in separate classes. A system of three-five tolerance classes might be a more effective way to take into account gradations in tolerance levels of species.

The soil and climate data are sometimes crude approxitions, necessarily resulting in some error. The program requires values for soil depth, texture, and moisture holding capacity. When attempting to predict growth patterns for comparison to field data, the soil characteristics may not be complete and estimations must be used. Temperature and precipitation data used for JABOWA were taken from North America isotherm maps and Ohio average monthly precipitation figures. This data may be too general to accurately reflect conditions in a specific area of Ohio.

The simulator relies heavily on the random number generator as is evidenced by previous mention. The model is predicting what could happen rather than what will happen. It does give the most probable occurence under given circumstances, but all limitations present in the real world are not represented in this model. This could lead to some variant results.

FUTURE USES:

As compared with many other states, Ohio has very little professional management activity. In previous decades, Ohio has been basically an agricultural state. Now, especially in the southeast, old farmlands have slipped back into forest. New owners have little knowledge of what their land is capable of producing in terms of salable timber, or how long they can expect to wait for the trees to reach a merchantable size. State forest managers have very little inventory data as a guide for management decisions, or how growth of trees will react to certain management practices.

A simulation such as JABOWA could be a valuable tool for forest managers to use as a guide for management decisions. The revised form of such a model would contain local climatic data with site information and representative species particular land being entered in the program by the user. This model will predict growth patterns resulting from certain management decisions, such as cutting, thinning or starting a monoculture plantation.

JABOWA would be a good tool for use in the classroom. Forest management students would be able to see results of management decisions reflected in growth patterns covering up to 500 years. Effects of different climatic areas or of changing site conditions on various species are reflected in the growth patterns. Possibly even examples of succession over 500 years could be represented by the model.

Further development of the program for more intensive future use could include developing a wildlife population model, along the same lines as JABOWA, to incorporate the animal component of the forest ecosystem with the plant. Enough research is being conducted in this area to supply adequate information for development of the model. The logical next step for a valid model is to expand it, without severely generalizing, each time making the model a little closer to being a true representation of the real world.

II. REVISION OF JABOWA TO OHIO DATA

Before validation of the simulator for Ohio conditions could begin, the base data and species list of the original JABOWA had to be revised. JABOWA was developed, as mentioned earlier, with information from and for use on the Hubbard-Brook Experimental Forest, located in New Hampshire.

Application to forests in other regions requires changes in species parameters such as species growth rate and leaf weight constants, maximum age, and maximum and minimum growing degree days. Changes in site variables such as temperature, precipitation, soil depth, texture and moisture capacity are also necessary. There is a program guide available for the specific purpose of adding new species and changing the simulation to other forest systems, simplifying the process of revision (1).

Species parameter values were located through textbooks of dendrology, silviculture and silvics (8 and 11). Growth and leaf weight constants were calculated from research reports or silvical descriptions. New values for site variables such as mean monthly precipitation and temperature were obtained from regional weather records. The necessary climatic data, such as average growing degree days for each species range, was derived from species range maps and regional weather records (7).

Thirteen species were chosen initially to represent Ohio forests. The species being used are walnut, white and red pine, tulip poplar, white and black oak, red and sugar maple, white ash, black cherry, hawthorn, red elm and shagbark hickory.

Using the aforementioned guide, the revisions were made and the program was ready for validation of its functional equations.

III. VALIDATION TECHNIQUE

Dr. James Brown, from the Ohio Agricultural Research and Development Center in Wooster, Ohio, has been conducting a study in two state forests, Mohican and Blue Rock, for connection between growth and soil conditions. He is studying thirty-year-old white pine plantations in both forests. While collecting data for his research, he also recorded the understory species on three milacre plots around selected sample trees. Each individual was categorized: less than 3' tall, 3' tall to 4" d.b.h., and greater than 4" d.b.h. Also recorded were soil depths at the sample tree and rockiness of soil, which are necessary for the JABOWA program. An example of the field data sheet is shown in the Appendix, Figure A. Five sample trees were selected, for differences in soil depths and rockiness, from two plantations on

Mohican State Forest.

Using Dr. Brown's data on white pine plantations, several plots were "set up" representing various site characteristics. The initial tree size and spacing were specified to depict an actual plantation based on this data.

The simulator's plot size is 32.8 feet by 32.8 feet (10 meter by 10 meter). The spacing for the white pine plantations were six by six and seven by seven feet. The five simulator plots contained sixteen and twenty five trees, according to the plantation spacing of six and seven feet. Since little is known about the initiation of the plantation, except the date, an original diameter of 0.236 inches was assumed for the white pine.

White pine monocultures were simulated by JABOWA and ingrowth patterns of hardwoods were recorded. Repeated runnings of the program led to general trends of understory species compositions. Output was obtained for each plot up to the age of the plantation, or thirty-eight years.

IV. TEST RESULTS AND CONCLUSIONS

I had hoped to show the validity of JABOWA in predicting understory ingrowth trends in a white pine plantation. I was interested in trends, rather than actual d.b.h. and basal area predictions, as an initial step in testing of the model. After revising the program to a completely different forest area, Ohio, I felt that the first step to testing the predictive values of the program should be in terms of trends of growth; i.e., does the simulated plot contain species also represented in the field plots? The next step would involve looking at valid predictions of d.b.h. and basal area of individuals.

In the appendix, Figure B, is a list of species and their number in the computer output. Figures C,D,E and F are examples of the species represented in field plots versus the final output of the program at thirty-eight years, the age of the particular plantation. Comparison will show that while the field plots contained mostly red maple,cherry, elm and white pine, the model plots contained, in general, black walnut, elm, white pine, and cherry. This discrepancy was maintained in each of the five plot conditions and in several program runs of each plot. Initial , nineteen year, and thirty-eight year composition are shown in the appendix. The program was consistent in what it predicted, but its trends were not consistent with field data trends.

In reviewing the simulation program, I have compiled a list of several factors which may be partially at fault for the contradictory trends. There are several site and species parameters for various relations which are part of the base data of the model. These required changing when the program was revised to Ohio conditions. As a first step, the factors should be tested and checked. If low correlation is found, the parameters can be adjusted and the program tested again. If the trends are still inconsistent with real data, a next step may be to look at the functional equations within the program. Changes in the equation constants or the form of the equations themselves may be necessary.

As mentioned elsewhere in this paper, the light tolerance classes are limited to tolerant or intolerant. This might pose a problem in that the trees used in the program are not readily aligned in two categories. As I suggested earlier, a system of three to five classes may be an improvement. Addition of such a system to JABOWA would require work beyond the scope of this paper.

Another source of error may be in the calculation of the annual amount of actual evapotranspiration (ET). This number is calculated in the program and is a function of the following: average monthly precipitation and temperatures, potential evapotranspiration (also calculated in the program), depth and texture of the soil, and the fraction of precipitation available for evapotranspiration. All of these parameters are possible sources of error. Average precipitation and temperature are approximations from climatic charts. Depth and texture of the soil are in some cases approximations. The fraction of precipitation available for ET could well be in error, since little information was used for its determination.

The value of annual amounts of actual ET is important in the program as it is a limiting factor for ingrowth of species. Each species has a minimum ET (WMIN) required for regeneration and growth of trees. If WMIN for a species is below the actual ET value calculated, that species will not regenerate. Some revision work had already been done before I began my work. WMIN was one of those values already revised. I am now considering the present values of WMIN as a source of error. As I am not aware of how these values were determined, I cannot check their validity. At this point, I have not found any data to help me do so. As a preliminary test, I changed values of this parameter, as follows, to observe any obvious changes in the simulation:

Species	Original WMIN	Changed WMIN
red maple	300.0	220.0 mm/yr.
shagbark hickory	250.0	240.0
black walnut	200.0	260.0
black oak	300.0	250.0

The results can be seen in the appendix, Figures C.3, D.3, E.3, and F.3. Before changing the parameter WMIN, the program consistently "grew" elm, walnut, and white pine. By changing the values, red maple was introduced and black walnut was unable to regenerate. The results compare more favorably with the field data.

However, another problem came into mind at this point. The program differs from the "real world" in the following respect: it assumes that,given proper conditions, all species are available to regenerate on its site. In the white pine plantations, this point is probably not so. I felt justified in raising the WMIN value of black walnut enough to keep it out, in this respect; there was no walnut in the field plots either because the moisture levels are too low or there is no seed source. However, once the black walnut was removed from the simulation picture, the ingrowth trends were much closer to those found in the field studies.

Work I have done on this model has given me greater insights into the development of a forest simulation. Data on many aspects of vegetation-site-environment interactions such as minimum ET values, relationships between leaf weight and area and tree diameter, tolerance values seem to be lacking. Further research on my part may turn up more precise temperature and precipitation data than that which I am using. Access to adequate field data may be a step in determining relations such as those mentioned above.

Though the results of my work have not materialized as I had hoped, I have gained great insights into the workings of this model. I have also formulated ideas concerning what approaches and data are needed to further improve the predictive validity for an Ohio forest ecosystem growth model.

APPENDIX

FIGURE A

SPECIES: WP
MAIN PLOT NO: 6 6x not used in testing
DATE PLANTED:
DATE EVALUATED: 9-4-74
EVALUATED BY: VROT

LOCATION AND IDENTIFICATION
County:
Forest or Owner:
Mailing Address:
Stand No: Sub-Plot No:

I: TOPOGRAPHIC DATA:
Aspect (azimuth), degrees: 330
Slope, percent: 17
Slope position: Ridge___; Upper X; Middle___; Lower___; Bottom___; Bench___
Slope length, yards: 800+___; 800___; 600___; 400___; 200 X; 100___; 50___; 0___
Slope shape: Concave___; Convex___; Even X
Extent: Slight___; Moderate X; Extreme___
Elevation, feet:

II: SOILS DATA:
Soil Profile; Depths, inches:
Total: 18" (to C)
Depth to mottling: None
Organic ("O"): 1/2"
A1 or Ap: 0-4
A2: —
B1: 4-6
B2: 6-15
B3: 15-18

Field Textures
loam
loam
clay loam to sandy clay
loam

Soil Type:
Degree and Type of Erosion: Mod to severe - Sheet
Other Comment (soils): Mod stony -- 35-40%

III: VEGETATIVE SAMPLE, milacre plots, from Tree No. 3

	Plot 1 (5', Az: 306)		Plot 2 (15', Az: 60)		Plot 3 (25', Az: 180)	
Herbaceous:						
Type (Br-Gr-Wd):	BR GR WD		BR WD		WD	
Density, %:	70 20 10		40 25		30	
Dom. Species:	GRAPE RASBERRY		FERN BLACKBERRY		CREEPER	
Woody:	Species	# Stems	Species	# Stems	Species	# Stems
Seedlings (-3'):	CHERRY S		BITTER HICK	1	B. OAK	1
	DOGWOOD		CHERRY WD	1		
			BL OAK	1 1		
			SASSIFRAS	1		
Saplings (3'-4"):			RED MAPLE	1	DOGWOOD	1
			GR ASH	1		
					11 WP	1
Overstory (+4"):						

IV: STAND INFORMATION:
Seedling and/or planting information:

Thinning and/or other cultural treatments:

Other:

SEE REVERSE SIDE FOR GENERAL PLOT LOCATION AND PLOT LAYOUT

FIGURE B

Species and Number as Used in JABOWA Output Format

1	WHITE ASH	FRAXINUS AMERICANA
2	RED MAPLE	ACER RUBRUM
3	SUGAR MAPLE	ACER SACCHARUM
4	RED ELM	ULMUS RUBRA
5	TULIP POPLAR	LIRIODENDRON TULIPIFERA
6	BLACK CHERRY	PRUNUS SEROTINA
7	SHAGBARK HICKORY	CARYA OVATA
8	HAWTHORN	CRATAEGUS SPP.
9	BLACK WALNUT	JUGLANS NIGRA
10	WHITE PINE	PINUS STROBUS
11	RED PINE	PINUS RESINOSA
12	WHITE OAK	QUERCUS ALBA
13	BLACK OAK	QUERCUS VELUTINA

FIGURE C.1 Field Plot 30 Understory

	milacre #1	milacre #2	milacre #3
-3'	5 red maple 6 white pine 1 dogwood 1 aspen	3 red maple 1 white pine 1 dogwood 2 aspen 1 cherry 1 sassfras	3 red maple 2 white pine 1 bitternut
3'-4"			
4"+		7" white pine	14" white pine

FIGURE C.2 Simulation Plot Ingrowth Using Field Plot 30 Site Data

ELEVATION (FEET)	SOIL DEPTH	PERCENT ROCK	GROWING DEGREE DAYS	INDEX OF ACTUAL ET
800	0.2	0	5229.1	251.7

YEAR 0 CONDITIONS

SPEC.	NUM.	BASAR. sq. feet	DBH inches									
10	25	0.008	0.236	0.236	0.236	0.236	0.236	0.236	0.236	0.236	0.236	0.236
			0.236	0.236	0.236	0.236	0.236	0.236	0.236	0.236	0.236	0.236
			0.236	0.236	0.236	0.236	0.236					
	25	0.008	LEAF AREA =	4.300								

YEAR 19 RUN 1

SPEC.	NUM.	BASAR.	DBH		
9	8	0.350	4.759	3.302	2.995...
10	27	1.127	3.055	3.040	3.025...
			2.907	2.893	2.879...
			2.755	2.742	2.730...
12	1	0.009	1.258		
	36	1.486	LEAF AREA =	803.905	

YEAR 38

SPEC.	NUM.	BASAR.	DBH		
4	2	0.022	1.958	0.440	
6	2	0.001	0.359	0.258	
9	6	1.340	10.515	7.702	6.081...
10	26	3.334	6.770	6.616	6.467...
			5.347	5.198	5.059...
			1.031	0.850	0.851...
12	4	0.057	3.189	0.415	0.363...
	40	4.755	LEAF AREA =	2548.730	

YEAR 19 RUN 2

SPEC.	NUM.	BASAR.	DBH		
4	3	0.165	3.667	2.954	2.847...
6	2	0.004	0.566	0.566	
10	25	1.010	3.097	3.081	3.065...
			2.926	2.911	2.897...
			2.351	1.459	0.536...
12	2	0.015	1.403	0.902	
	32	1.202	LEAF AREA =	683.902	

YEAR 38

SPEC.	NUM.	BASAR.	DBH		
4	3	1.999	19.019	2.108	0.255.,
6	2	0.110	3.267	3.254	
9	3	0.038	2.151	1.514	0.274
10	26	2.775	6.189	6.027	5.875...
			4.824	4.743	4.666...
			1.425	0.291	0.305...
12	5	0.067	3.300	0.655	0.528...
	39	4.995	LEAF AREA =	2853.437	

FIGURE C.3 Simulation Plot with WMIN Changes Using Field Plot 30 Site Data

ELEVATION (FEET)	SOIL DEPTH	PERCENT ROCK	GROWING DEGREE DAYS	INDEX OF ACTUAL ET
800	0.2	0	5229.1	251.7

RUN 1

YEAR 19

SPEC.	NUM.	BASAR.	DBH		
9	5	0.314	4.786	3.580	3.012...
10	31	1.151	3.071	3.055	3.040...
			2.921	2.906	2.892...
			2.767	2.754	2.741...
12	1	0.009	1.260		
	37	1.474	LEAF AREA = 800.870		

YEAR 38

SPEC.	NUM.	BASAR.	DBH		
2	1	0.048	2.953		
4	2	0.002	0.441	0.322	
6	3	0.002	0.439	0.337	0.310
9	9	1.364	10.407	7.668	6.492...
10	26	3.472	6.849	6.601	6.539...
			5.461	5.355	5.254...
			1.395	1.387	0.918...
12	3	0.006	0.761	0.642	0.279
	44	4.893	LEAF AREA = 2623.675		

RUN 2

YEAR 19

SPEC.	NUM.	BASAR.	DBH		
2	4	0.471	6.601	4.474	4.694...
4	2	0.486	8.433	4.240	
6	8	0.302	4.987	4.825	2.526...
10	25	1.053	3.089	3.071	3.049...
			2.918	2.903	2.887...
			2.755	2.260	0.628...
13	1	0.056	3.201		
	40	2.369	LEAF AREA = 1205.808		

YEAR 38

SPEC.	NUM.	BASAR.	DBH		
2	4	0.897	12.397	3.600	1.212...
4	4	4.067	25.677	9.259	0.268...
6	2	0.239	6.615	0.223	
10	19	1.465	4.397	4.323	4.248...
			3.803	3.758	3.707...
12	2	0.001	0.358	0.318	
13	3	0.185	5.805	0.279	0.305
	34	6.855	LEAF AREA = 3891.686		

FIGURE D.1 Field Plot 36 Understory

	milacre #1	milacre #2	milacre #3
-3'	3 red maple 6 cherry 3 dogwood	7 red maple 3 cherry 3 slip. elm 1 black oak	1 red maple 7 cherry 3 slip. elm 1 m. hickory
3'-4"			
4"+			12" white pine

FIGURE D.2 Simulation Plot Ingrowth Using Field Plot 36 Site Data

ELEVATION (FEET)	SOIL DEPTH	PERCENT ROCK	GROWING DEGREE DAYS	INDEX OF ACTUAL ET
800	0.2 M.	0	5229.1	251.7

YEAR 0 CONDITIONS

SPEC.	NUM.	BASAR. SQ.FT.	DBH inches									
10	16	0.005	0.236	0.236	0.236	0.236	0.236	0.236	0.236	0.236	0.236	0.236
			0.236	0.236	0.236	0.236	0.236	0.236				
	16	0.005	LEAF AREA = 2.756									

YEAR 19 RUN 1

SPEC.	NUM.	BASAR.	DBH		
4	3	0.315	7.072	2.524	1.188
6	2	0.186	5.231	2.575	
9	5	0.301	7.354	0.758	0.357...
10	15	0.757	3.178	3.160	3.142...
			2.994	2.978	2.962...
12	3	0.031	1.730	1.127	1.154
	28	1.589	LEAF AREA = 804.016		

YEAR 19 RUN 2

SPEC.	NUM.	BASAR.	DBH		
4	5	1.965	17.790	4.737	4.576...
6	7	0.077	2.518	1.752	1.817...
10	17	0.596	2.695	2.681	2.668...
			2.562	2.549	2.537...
12	6	0.016	1.207	0.663	0.667...
	35	2.654	LEAF AREA = 1551.900		

YEAR 38

SPEC.	NUM.	BASAR.	DBH		
4	7	3.710	25.140	5.203	2.690...
6	5	0.560	8.636	5.249	0.553...
9	7	0.982	13.026	2.286	1.549...
10	12	1.241	4.845	4.765	4.688...
			4.022	3.783	
12	3	0.122	3.239	2.425	2.465
	34	6.615	LEAF AREA = 3502.506		

YEAR 38

SPEC.	NUM.	BASAR.	DBH		
4	3	0.031	1.255	1.004	1.210
6	4	0.478	6.832	3.750	3.709...
9	7	0.036	2.073	1.238	0.433...
10	18	1.539	4.917	4.837	4.760...
			4.130	4.084	4.031...
12	8	0.167	3.100	2.235	2.239...
	40	2.250	LEAF AREA = 1064.895		

FIGURE D.3 Simulation Plot with WMIN Changes Using Field Plot 36 Site Data

ELEVATION (FEET)	SOIL DEPTH	PERCENT ROCK	GROWING DEGREE DAYS	INDEX OF ACTUAL ET
800	0.2	0	5229.1	251.7

RUN 1

YEAR 19

SPEC.	NUM.	BASAR.	DBH		
2	4	0.160	4.624	2.244	1.591 ...
4	2	0.005	0.709	0.590	
6	4	0.178	5.194	2.334	0.285 ...
10	23	0.866	3.072	3.056	3.040 ...
			2.919	2.904	2.890 ...
			0.657	0.679	1.245
12	1	0.001	0.392		
	34	1.210	LEAF AREA = 600.739		

YEAR 38

SPEC.	NUM.	BASAR.	DBH		
2	5	0.781	8.405	7.018	4.813
4	5	0.600	7.005	6.801	2.073...
6	5	1.231	14.424	2.716	3.121
10	23	2.754	6.365	6.215	6.659...
			5.651	4.352	4.262...
			0.712	6.255	
12	3	0.021	1.088	0.842	0.390...
13	1	0.015	1.676		
	42	5.402	LEAF AREA = 2525.948		

RUN 2

YEAR 19

SPEC.	NUM.	BASAR.	DBH		
2	4	0.011	0.936	0.817	0.389..
4	3	0.943	11.312	6.381	2.035
6	2	0.045	2.841	0.454	
10	12	0.503	2.956	2.936	2.910 ..
			2.773	1.477	
12	1	0.004	0.854		
13	3	0.412	5.958	5.666	2.795
	25	1.918	LEAF AREA = 1113.473		

YEAR 38

SPEC.	NUM.	BASAR.	DBH		
2	5	0.146	2.987	2.783	1.980...
4	2	4.392	26.760	13.421	
10	2	0.146	3.677	3.620	
13	9	1.142	9.830	9.139	5.141 ...
	18	6.326	LEAF AREA = 3796.474		

FIGURE E.1 Field Plot 37 Understory

	milacre #1	milacre #2	milacre #3
-3'	1 dogwood	1 red maple	1 m. hickory
3'-4"			
4"+	11.7" white pine	11.6" white pine	11.1"white pine

FIGURE E.2 Simulation Plot Ingrowth Using Field Plot 37 Site Data

ELEVATION (FEET)	SOIL DEPTH	PERCENT ROCK	GROWING DEGREE DAYS	INDEX OF ACTUAL ET
300	0.2	35	5229.1	193.4

YEAR 0

SPEC.	NUM.	BASAR.	DBH
10	16	0.005	0.236 0.236 0.236 0.236 0.236 0.236 0.236 0.236 0.236 0.236 0.236 0.236 0.236 0.236 0.236 0.236
	16	0.005	LEAF AREA = 2.756

RUN 1

YEAR 19

SPEC.	NUM.	BASAR.	DBH
10	15	0.730	3.097 3.081 3.065... 2.942 2.910 2.902...
	15	0.730	LEAF AREA = 412.852

YEAR 38

SPEC.	NUM.	BASAR.	DBH
10	12	2.437	7.052 6.879 6.621 ... 5.394 5.289
	12	2.437	LEAF AREA = 1377.769

RUN 2

YEAR 19

SPEC.	NUM.	BASAR.	DBH
10	13	0.719	3.303 3.284 3.260... 3.100 3.082 3.065
	13	0.719	LEAF AREA = 400.701

YEAR 38

SPEC.	NUM.	BASAR.	DBH
10	9	2.028	7.161 6.960 6.800..
	9	2.028	LEAF AREA = 1146.956

FIGURE E.3 Simulation Plot with WMIN Changes Using Field Plot 37 Site Data

ELEVATION (FEET)	SOIL DEPTH	PERCENT ROCK	GROWING DEGREE DAYS	INDEX OF ACTUAL ET
800	0.2	35	5229.1	193.4

RUN 1

YEAR 19

SPEC.	NUM.	BASAR.	DBH		
10	15	0.820	3.290	3.277	3.258 ...
			3.111	3.083	3.065 ...
	15	0.820	LEAF AREA = 463.066		

YEAR 38

SPEC.	NUM.	BASAR.	DBH		
10	12	2.437	7.052	6.870	6.621 ...
			5.394	5.289	
	12	2.437	LEAF AREA = 1377.769		

RUN 2

YEAR 19

SPEC.	NUM.	BASAR.	DBH		
10	13	0.722	3.301	3.282	3.263 ...
			3.115	3.097	3.080
	13	0.722	LEAF AREA = 408.204		

YEAR 38

SPEC.	NUM.	BASAR.	DBH		
10	12	2.509	7.083	6.823	6.657 ...
			5.549	5.436	
	12	2.509	LEAF AREA = 1418.652		

FIGURE F.1 Field Plot 39 Understory

	milacre #1	milacre #2	milacre #3
-3'	3 red maple 4 dogwood 1 sassafras	1 red maple 2 cherry 1 tulip	3 red maple 1 dogwood
3'-4"			
4"+		9.9" white pine	

FIGURE F.2 Simulated Plot Ingrowth Using Field Plot 39 Site Data

ELEVATION (FEET)	SOIL DEPTH	PERCENT ROCK	GROWING DEGREE DAYS	INDEX OF ACTUAL ET
800	0.2	8	5229.1	221.4

YEAR 0 CONDITIONS

SPEC.	NUM.	BASAR. sq. feet	DBH inches									
10	16	0.005	0.236	0.236	0.236	0.236	0.236	0.236	0.236	0.236	0.236	0.236
			0.236	0.236	0.236	0.236	0.236	0.236				
	16	0.005	LEAF AREA =	2.756								

YEAR 19 RUN 1

SPEC.	NUM.	BASAR.	DBH		
4	2	0.461	6.924	6.043	
9	13	0.573	5.597	5.487	4.933 ...
			0.384	0.396	0.319 ...
10	16	0.623	2.926	2.911	2.885 ...
			2.751	2.738	2.721 ...
	31	1.657	LEAF AREA =	898.238	

YEAR 19 RUN 2

SPEC.	NUM.	BASAR.	DBH		
4	9	1.970	17.722	4.715	4.555 ...
9	3	0.039	2.115	1.539	0.494
10	23	0.610	2.688	2.674	2.661 ...
			2.555	2.543	2.531 ...
			0.461	0.262	0.509 ...
	35	2.618	LEAF AREA =	1500.120	

YEAR 38

SPEC.	NUM.	BASAR.	DBH		
4	2	4.665	24.109	16.534	
9	10	0.811	8.814	7.054	4.410 ...
10	12	0.857	4.081	4.021	3.959 ...
			3.486	0.402	
	24	6.333	LEAF AREA =	3696.198	

YEAR 38

SPEC.	NUM.	BASAR.	DBH		
4	5	0.046	1.340	1.359	1.481 ...
9	9	0.318	5.606	4.626	1.880 ...
10	26	1.623	4.901	4.822	4.740 ...
			4.131	4.077	4.024 ...
			0.753	0.698	0.707 ...
	40	1.937	LEAF AREA =	1092.920	

FIGURE F.3 Simulation Plot with WMIN Changes Using Field Plot 39 Site Data

ELEVATION (FEET)	SOIL DEPTH	PERCENT ROCK	GROWING DEGREE DAYS	INDEX OF ACTUAL ET
800	0.2	8	5229.1	221.4

YEAR 19 RUN 1

SPEC.	NUM.	BASAR.	DBH		
2	6	0.167	4.997	1.257	1.262 ...
4	3	0.683	7.656	8.126	0.679
10	21	0.664	2.910	2.895	2.881 ...
			2.763	2.750	2.735 ...
	30	1.515	LEAF AREA = 873.635		

YEAR 38

SPEC.	NUM.	BASAR.	DBH		
2	10	1.461	11.625	5.931	5.915 ...
4	7	0.267	5.647	3.204	1.635 ...
10	19	1.562	5.010	4.929	4.850 ...
			4.264	4,192	3.090 ...
	36	3.290	LEAF AREA = 1768.372		

YEAR 19 RUN 2

SPEC.	NUM.	BASAR.	DBH		
2	7	0.132	3.143	2.621	1.971 ...
4	3	0.219	5.103	3.646	0.936
10	17	0.738	3.121	3.102	3.085 ...
			2.948	2.932	2.909 ...
	27	1.090	LEAF AREA = 616.261		

YEAR 38

SPEC.	NUM.	BASAR.	DBH		
2	12	0.936	8.201	7.180	4.96[illegible] ...
			0.210	0.238	
4	5	3.509	20.947	13.319	5.158 ...
10	20	1.444	4.965	4.874	4.793 ...
			4.144	3.695	3.411 ...
	37	5.890	LEAF AREA = 3412.900		

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